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Status of the Yucca Moth (*Tegeticula yuccasella*) in Alberta

Alberta Wildlife Status Report No. 44

Alberta Conservation Association

Funded by Alberta Anglers, Hunters, and Other Conservationists

Alberta
SUSTAINABLE RESOURCE DEVELOPMENT

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Status of the Yucca Moth (*Tegeticula yuccasella*) in Alberta

Prepared for:
Alberta Sustainable Resource Development (SRD)
Alberta Conservation Association (ACA)

Prepared by:
Donna Hurlburt

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Series Editors: Sherry Feser and Robin Gutsell
Illustrations: Brian Huffman

For copies of this report, contact:
Information Centre - Publications
Alberta Environment/Alberta Sustainable Resource Development
Fish and Wildlife Division
Main Floor, Great West Life Building
9920 - 108 Street
Edmonton, Alberta, Canada T5K 2M4

Telephone: (780) 422-2079

OR

Information Service
Alberta Environment/Alberta Sustainable Resource Development
#100, 3115 - 12 Street NE
Calgary, Alberta, Canada T2E 7J2

Telephone: (780) 297-3362

OR

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PREFACE

Every five years, the Fish and Wildlife Division of Alberta Sustainable Resource Development reviews the status of wildlife species in Alberta. These overviews, which have been conducted in 1991, 1996 and 2000, assign individual species "ranks" that reflect the perceived level of risk to populations that occur in the province. Such designations are determined from extensive consultations with professional and amateur biologists, and from a variety of readily available sources of population data. A primary objective of these reviews is to identify species that may be considered for more detailed status determinations.

The Alberta Wildlife Status Report Series is an extension of the general statusing exercises (1996 *Status of Alberta Wildlife, The General Status of Alberta Wild Species* 2000), and provides comprehensive current summaries of the biological status of selected wildlife species in Alberta. Priority is given to species that are potentially at risk in the province ("At Risk," "May Be At Risk"), that are of uncertain status ("Undetermined"), or those considered to be at risk at a national level by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC).

Reports in this series are published and distributed by the Alberta Conservation Association and the Fish and Wildlife Division of Alberta Sustainable Resource Development. They are intended to provide detailed and up-to-date information which will be useful to resource professionals for managing populations of species and their habitats in the province. The reports are also designed to provide current information which will assist the Alberta Endangered Species Conservation Committee to identify species that may be formally designated as "Endangered" or "Threatened" under Alberta's *Wildlife Act*. To achieve these goals, the reports have been authored and/or reviewed by individuals with unique local expertise in the biology and management of each species.

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) conducted the technical review of this report and will use this Alberta status report to evaluate the status of the yucca moth in Canada.

EXECUTIVE SUMMARY

The yucca moth (*Tegeticula yuccasella*) is distributed throughout the United States and just reaches Canada in the Milk River region. The species currently has no status designations in Canada; although its host plant, the soapweed (*Yucca glauca*), has been designated as "Threatened" by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2001). This report is intended to summarize existing information on the yucca moth and to assist in the management of the moth, its mutualist host and their habitat in Alberta.

The yucca moth is the only pollinator and a critical seed predator of a long-lived, grassland perennial plant called soapweed. The two species are involved in a unique obligate mutualism where neither species can survive for long periods of time without the other. The species occurs at two confirmed sites in Alberta along the Milk River (Pinhorn population) and its tributary, the Lost River (Onefour population).

The population size of yucca moths in Alberta varies greatly within and among years and without long-term data it is difficult to determine whether numbers are sufficient to sustain the species. In Onefour, moths occur in similar densities to populations farther south; however moths are notably absent from the Pinhorn population. Threats to the survival of the moth are most likely related to its northerly distribution and to population isolation of the host plant. Other threats not related to latitude include herbivory by wild ungulates and insects, habitat alteration, and the collection of plants for horticultural purposes.

Yucca moths have probably never been abundant in Alberta given the species' northern, peripheral distribution, although there is evidence that the soapweed has spread north over the last 20 years. The nearest population of moths is over 200 km south of both sites, and both the plant and the moth have developed some unique strategies relative to other populations. Further, the intimate relationship between the moth and the soapweed represents the very basis of food web interactions and is an excellent model for demonstrating the importance of preserving communities instead of single species. The soapweed and its yucca moth are an intriguing example of our native flora and fauna and we should strive to ensure the persistence of both species.

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INTRODUCTION

Tegeticula yuccasella (Riley) is the only species of yucca moth native to Alberta, and has a mutualistic relationship with its host, the soapweed (*Yucca glauca* Nuttall) in Canada. The interaction between the moth and plant is beneficial for both (mutualistic) and both species have evolved specific morphologies and behaviours to ensure the interaction persists (coevolved). The moth also has several other host species of the genus *Yucca* in the United States. The yucca and yucca moths have an obligate relationship, which means that neither species can survive without the other. Moth larvae feed only on yucca seeds, and in turn, yuccas can produce seed only if they are pollinated by yucca moths. The moth is widely distributed in the United States with its northern limits just crossing the United States / Canada border in the Milk River region. In Alberta, the yucca moth is only known from south-facing coulee slopes in the Dry Mixed Grass Subregion (ANHIC 2001). Although there are only two native populations of moths in Alberta and one of them is in decline, the species has no special designation as a rare species by either the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) or by the province of Alberta.

This report summarizes available information on the biology of the yucca moth *(T. yuccasella)*, with emphasis on populations in Alberta, as a step in assessing the status of the species in the province.

HABITAT

In Alberta, yucca moths are restricted to the Dry Mixed Grass Subregion (ANHIC 2001). This semi-arid region has a continental climate with extremes of weather and large daily and seasonal variation in temperature. This subregion has a typical continental climate that is characterized by low precipitation, hot summers and a high rate of evaporation. The rate of evaporation is exacerbated by a high average wind speed, often approaching 100 km/hr.

At the northern edge of its range in Alberta and Montana, the yucca moth uses only soapweed for oviposition and for larval feeding. This plant grows in sparsely distributed populations on well-drained, mostly south-facing coulee slopes. Typically these slopes are eroded, dry and sparsely vegetated with prickly-pear cactus (*Opuntia polyacantha*) and sagebrush (*Artemisia cana*). At the northern limits of the species' range (north of the Missouri River, Montana), natural populations have only been found on kame slopes associated with the last glaciation period (D. Hurlburt, pers. obs.). The aspects of slopes supporting soapweed in Alberta range from 34° (northeast) to 200° (south-southwest), and generally face away from prevailing southwest winds, except in cases where slopes are protected by adjacent slopes. Soils tend to be alkaline and regosolic in nature without shallow hardpan (Milner 1977, Fairbarns 1984). In areas farther south (northern Wyoming), yucca plants grow on flatter ground and occurs in sand dunes, pine forest and glades in the east and grassland in the southwest ranging in altitude from 0 to 1920 m (Pellmyr 1999).

CONSERVATION BIOLOGY

There is no known literature available on the conservation biology of the yucca moth, even though yuccas and their pollinators are common throughout the United States and Mexico. Aspects of the moth's life cycle, population dynamics of the soapweed and the obligate relationship between the two species must be considered to assess the status of the moth. Further, peripheral and isolated populations of yucca moths have important implications for the management and preservation of the yucca moth and its host.

1. Life Cycle of the Yucca Moth. - Most adult moths emerge from the soil from the second week in June through to the second week in July

(D. Hurlburt, unpubl. data). Shortly after emergence they gather and mate in freshly opened soapweed flowers (Riley 1892, Baker 1986, Addicott et al. 1990). Adult female yucca moths actively collect pollen from one plant then usually fly to another inflorescence. Upon finding a fresh flower, a female first inserts her ovipositor through the carpel wall and lays an egg next to the developing ovules (Aker and Udovic 1981, Addicott and Tyre 1995). She then climbs to the tip of the style, and using her maxillary tentacles (appendages unique to yucca moths), she actively transfers pollen into the stylar canal. Moths do not feed as adults and die after three to five days. Moth eggs hatch after seven to 10 days (and upon hatching, larvae feed on developing seeds). After approximately 50-60 days, 4th instar larvae chew their way out of the yucca fruit and drop to the ground via a silken thread (Riley 1892). Larvae burrow 5-20 cm into the soil (Fuller 1990), spin a cocoon of silk and sand particles (Davis 1967) and enter a prepupal diapause (dormancy) (Riley 1873, Keeley et al. 1984). After a minimum diapause of 1 year, larvae pupate and emerge from the soil as adults usually coinciding with yucca flowering.

Fuller (1990) was the first to demonstrate that *T. yuccasella* are capable of prolonging diapause for at least four years. Most larvae terminated diapause during or before their second year. This ability to extend diapause for a minimum of three years was confirmed in Alberta populations; however, up to 50% of observed larvae failed to pupate and of those that pupated, half died in the cocoon (D. Hurlburt, unpubl. data). Diapause may be prolonged for up to 30 years as observed in a closely related species, *Prodoxus y-inversus* (Powell 2001); however there is no such data available for *T. yuccasella* to support this idea.

Prolonged diapause is suggested to have favourable adaptive value in habitats where resources are available for short periods of time per season or vary considerably from year to year (Powell 1989). Since yucca moths must be closely synchronized with the development of inflorescences of their host plants to reproduce and because soapweed flowering at the northern limits of their range are highly variable among years, the existence of prolonged diapause is likely. However, it is suspected that only a small proportion of individuals will actually exhibit such a strategy and that most yucca moths will emerge in less than two years, i.e., most moths will have a generation time of less than two years. Fuller (1990) found that only 9% of moth larvae in diapause were alive at the end of his third year of study and that approximately 50% died in their cocoons each winter. Nonetheless, the persistence of a few individuals in the soil may be a bet-hedging strategy for moths to bypass unfavourable climatic or biological conditions such as poor flowering.

2. Soapweed Biology and Dynamics - Soapweed, a relative of century plants (*Agave* spp.), is the only yucca native to Canada. It is an arid-region perennial that flowers every two to three years in Alberta. The growth form of the plant is a single rosette or cluster of rosettes of narrow, spear-shaped leaves 25 cm to 40 cm long. An inflorescence 30 cm to 85 cm tall can grow from the center of each rosette and produce 15 to 75 large, fleshy, white flowers that mature from the base toward the apex of the inflorescence. Individual rosettes die after producing an inflorescence (Kingsolver 1984).

Sexual reproduction or fruit production can only take place if flowers are pollinated by yucca moths. In Alberta, the Pinhorn population has failed to reproduce sexually (no seed production) in a minimum of five years and the Onefour population has shown low fruit set in three of four years studied (Hurlburt 2001). However, soapweed are also capable of asexual or clonal reproduction. New rosettes are produced in late summer from lateral buds from the rhizome near senescing[1] rosettes. Kingsolver (1984) found the rate of asexual reproduction increased during times or in locations where little sexual reproduction ocurred. In Alberta, the Pinhorn

[1] Senescing - The process of aging.

population has significantly more rosettes (i.e. higher levels of asexual reproduction) than other populations in the north (D. Hurlburt, unpubl. data), supporting Kingsolver's observations. Although individual rosettes die a couple years after flowering (and do not produce more inflorescences), clones can persist for many years. Longevity data for soapweed clones are not available but there is anecdotal evidence to suggest that plants live for 25-50 years (J. Addicott, pers. comm.). In Alberta, soapweed only reproduces after 15-20 years of age (D. Hurlburt, unpubl. data).

Inflorescences are capable of maturing five or six fruit at the northern edge of their range. Soapweed fruit contain six locules (rows) of 30-50 seeds that are flat and easily dispersed by wind when the fruit dehisces[2] in September. Seeds overwinter and germinate the following spring; however, recruitment is very low; less than 1% of each Canadian population consists of seedlings less than 10 cm tall. Of 1000 seeds planted in 1999, only three successfully germinated (D. Hurlburt, unpubl. data). Recruitment for populations throughout the range is normally low (1-2%); however, recruitment in Alberta is significantly lower than elsewhere in the species' range. Seeds contain no endosperm and are incapable of laying dormant for longer than a year (J. Addicott, pers. comm.); therefore, consideration of the seedbank is not relevant to the persistence of the species.

In Canada, soapweed is recognized as "Threatened" by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) because of population isolation, the species' limited, peripheral distribution and its obligate reliance on the yucca moth for pollination (Fairbarns 1984, Csotonyi and Hurlburt 1999, COSEWIC 2002).

3. Mutualistic Relationship between Yucca Moth and Soapweed - Of crucial importance to the survival of the yucca moth is the survival and sexual reproduction of its host, the yucca. The plant and moth have an obligate mutualistic relationship and neither species can survive without the other. Obligate mutualistic systems are those relationships in which each partner requires the other to survive or reproduce, and as a result, both species benefit from the interaction (Addicott 1995). This interaction is obligate for both yuccas and yucca moths, because there is no other consistently successful mechanism of pollen transfer for the plants and because yucca moth larvae feed only on yucca seeds.

The maintenance of the mutualism is dependent upon the degree of overlap of appropriate life history stages between the plant and its pollinator. In this case, pollinating moths must be active when flowers are receptive to pollen. Soapweed have developed several unique strategies for dealing with this problem in Alberta. Flowering of soapweed in Alberta is highly asynchronous, having the longest flowering season (approx. 83 days in 1998) of any documented soapweed population or any population of *Yucca* spp. (D. Hurlburt, unpubl. data). In species of yucca with similar numbers of flowers, flowering typically lasts around 30-35 days (J. Addicott, pers. comm). Further moth density is relatively constant throughout the flowering season; data suggest that flowers have an equal chance of being pollinated at any point during the flowering season (D. Hurlburt, unpubl. data).

In most populations, yuccas are predominantly an outcrossing[3] species and selective abscission[4] (abortion) of flowers occurs in response to self-pollination. However, at the northern edge of

[2] Dehisces - In yuccas, this refers to the cracking open of dried fruit and the subsequent dispersal of seeds.

[3] Out-crossing - Flowers are pollinated from another plant, rather than a flower on the same plant (self-fertilization). Some species or populations of plants have mechanisms, such as abortion of self-fertilized flowers, to ensure that outcrossing occurs.

[4] Abscission - The process of aborting or dropping leaves, flowers and/or fruit. Also, soapweed will abscise flowers that are heavily infested with yucca moth larvae to ensure that they have some seeds left for germination.

yucca's range, neither the presence of moths, nor the presence of other individual plants in flower is reliable and data suggest that yuccas were selected to be tolerant of a self-pollinating mating system (D. Hurlburt, unpubl. data). In Alberta and parts of Montana, if yuccas have a choice between cross-pollinated and self-pollinated flowers, they will choose to retain cross-pollinated flowers. However, if not given a choice, they will retain self- and cross-pollinated flowers equally with no apparent loss in seed viability (D. Hurlburt, unpubl. data).

4. Importance of Plant-Pollinator Relationships. - Recently, the importance of plant-pollinator interactions to society has been documented; several works have called attention to pollination as one of the most critical ecological interactions in the provision of food supply in agriculture and in nature (Bond 1994, Buchmann and Nabhan 1996, Kearns and Inouye 1997). Pollination systems are under increasing threat from human disturbance, including habitat fragmentation, changes in land use and agricultural practices, use of chemicals, and invasions of alien species; and as a result, the world is in a state of "pollination crisis" (Buchmann and Nabhan 1996). Despite the fact that they are ecologically, aesthetically and potentially economically important, we know little about wild pollinators that are not deemed important in commercial agriculture (Kearns and Inouye 1997). Mutualistic relationships, such as those between plants and pollinators, epitomize the essence of food-web interactions. The fate of many plants may depend on preserving their mutualistic relationships with both pollinators and the web of organisms that affect both plant and pollinator (Bond 1994, Kearns and Inouye 1997).

DISTRIBUTION

1. Alberta. - Yucca moths exist in sustainable numbers at only one of two naturally occurring soapweed populations in southeastern Alberta (Figure 1; Appendix 2). The Lost River (Alberta) population is primarily distributed along a 2-km stretch of south-facing coulee slope along a tributary of the Milk River (49°00' N, 110°26' W; elevation 870 m), on land owned by the Lethbridge Agricultural Research Substation in Onefour, Alberta. In the last four years, only a single pollinating female was known from the Pinhorn Grazing Reserve along a 0.05-km stretch of southwest-facing coulee on the Milk River drainage (49°05' N, 110°50' W; elevation 1000 m) and no larvae were found in prepupal diapause upon sifting twenty 2-litre samples of soil from around the bases of soapweed clones (D. Hurlburt, unpubl. data). Soapweed has not sexually reproduced (i.e., produced fruit) in this area for a minimum of five years and there has been no evidence of pollination or oviposition in abscised flowers. The moths in this population appear to be undergoing extirpation through the herbivory of soapweed stalks by wild ungulates (Hurlburt 2001). Although small numbers of soapweed plants are found in several other locations in Alberta, there has been no sign of fruit set or oviposition, indicating that adult moths are not present (Hurlburt 2001).

2. Other Areas. - *T. yuccasella* is found in yucca populations throughout the Great Plains from the southern boundary of Texas to southern Canada, and in all regions east of the plains northward to Michigan and Connecticut (Pellmyr 1999). The species is known to pollinate several different species of yucca and as a result has a much wider distribution than soapweed (Figure 2).

POPULATION SIZE AND TRENDS

1. Alberta. - An Alberta census of yucca moth and soapweed populations was completed for the first time in 1998 (Csotonyi and Hurlburt 1999). Every clone and fruit at both sites were documented and the number of emergence holes counted. Each emergence hole was formed by the emergence of a single yucca moth larva. Since 1998, pollinators have been monitored at these sites for three additional years (1999, 2000, 2001), using estimates or indices, as it was not

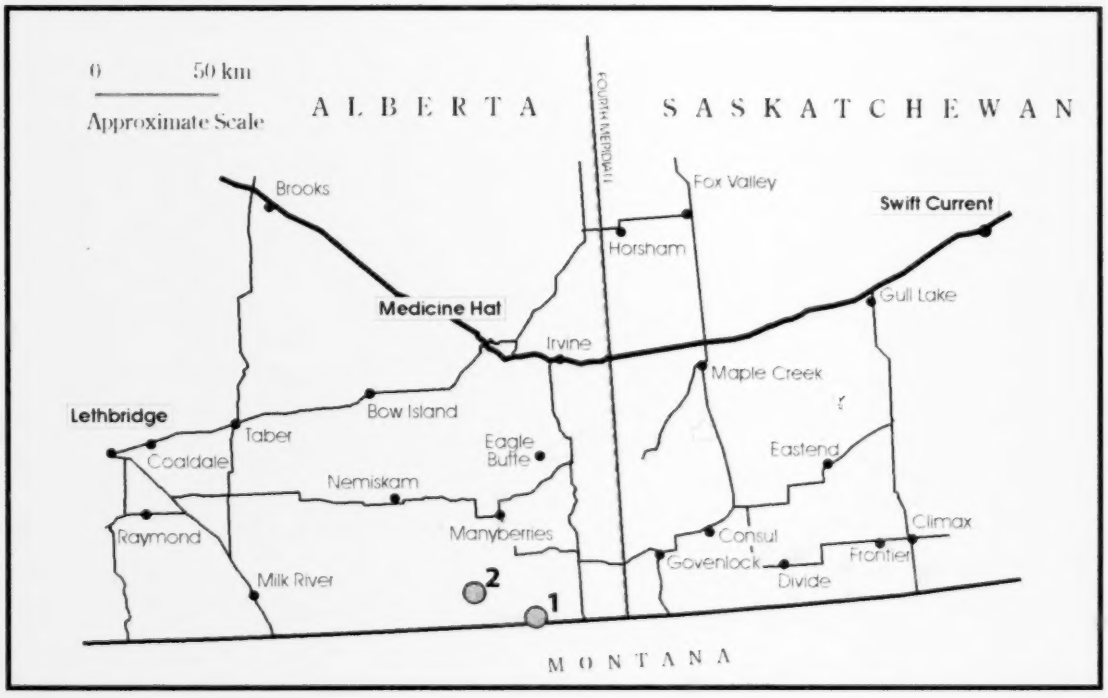

Figure 1. Known occurrences of the yucca moth (*Tegeticula yuccasella*) in Canada (Alberta). Numbers correspond to detailed descriptions of locations included in Appendix 2.

Figure 2. Distribution of the yucca moth, *Tegeticula yuccasella*, in North America.

always practical to collect data on every fruit. Moth abundance was assessed directly and indirectly in a proportion of fruit and plants in each population through 1) moth counts in fresh flower surveys, 2) larval counts within fruit, 3) fruit set per inflorescence, and 4) numbers of oviposition marks per fruit. These measures were not assessed every year because of high variation in flowering, moth abundance and herbivory; for example, there were few to no fruit produced in some years and/or locations.

Two native populations of *Y. glauca* exist in Alberta representing a total population size of potentially reproducing plants consisting of 29 557 rosettes in 8903 clones (Csotonyi and Hurlburt 1999). The Onefour population was estimated at 28 174 rosettes distributed among 8499 clones (Csotonyi and Hurlburt 1999) along coulee slopes and adjacent prairie. The Pinhorn population consisted of approximately 1383 rosettes among 404 clones (Csotonyi and Hurlburt 1999.

In 1998, there were only 255 yucca moths (including males, which do not pollinate) produced at Onefour from 29 557 rosettes of soapweed, an average of 4.397 + 0.350 larvae per fruit. A similar census at Pinhorn in 1998 revealed no fruit and no evidence of pollinators. In Pinhorn during four years of study, only one female pollinating moth has been observed, no pollinators have been found in diapause in the soil, and there has been no oviposition, nor fruit set (D. Hurlburt, unpubl. data). Data for measures of yucca moth abundance in Canada are presented in Table 1; comparable data from the United States are located in Appendix 2. Moth abundance in the Onefour population (Table 1) appears to be similar to moth abundance throughout the United States (Appendix 2).

With the exception of a single population in Colorado (Dodd 1989, Dodd and Linhart 1994), all other reports of moth abundance are substantially higher than those at Pinhorn. Dodd (1989) and Dodd and Linhart (1994) suggested that the population in Colorado suffered from an absence of moths because of the larvae's inability to complete development at high elevations and a low density of host plants; a similar response would be expected in small, northern edge populations such as at Pinhorn.

Without long-term data it is not known whether moth populations are increasing, decreasing or stable at Onefour. Considerable variation in moth abundance exists in all soapweed populations within and among flowering seasons

Table 1. Indices of yucca moth (*Tegeticula yuccasella*) population size in Alberta from 1998-2000.

	Fruit / Inflorescence	Moths / flower	# Larvae / fruit	Ovipositions / fruit
Onefour				
1998	2.034 + 0.279	Not monitored	4.397 + 0.350*	Not monitored
1999	3.102 + 0.161	0.456 + 0.259	3.560 + 0.470	9.552 + 1.261
2000	0.322 + 0.156	0.563 + 0.259	5.920 + 0.508	18.317 + 2.075
2001	1.411 + 0.115	0.388 + 0.235	4.396 + 0.576	14.755 + 1.489
Pinhorn				
1998	0.000 + 0.000	Not monitored	N/A - No fruit	Not monitored
1999	0.000 + 0.000	0.003 + 0.000	N/A - No fruit	0.000 + 0.000
2000	0.000 + 0.000	0.000 + 0.000	N/A - No fruit	0.000 + 0.000
2001	0.000 + 0.000	0.000 + 0.000	N/A - No fruit	0.000 + 0.000

* Based on # emergence holes per fruit in 1998. Actual counts of moth larvae per fruit are presented for 1999-2001.

and only long-term studies will provide insight on the viability of populations. Other insects are known to experience huge swings in population dynamics and continue to be sustainable; however, there is no literature to suggest that similar dynamics occur in yucca moths or the Prodoxidae. Further, small populations may be unable to recover from dips in population numbers as well as larger populations, and may be more susceptible to decline in response to stochastic events.

2. Other areas. - There are no long-term estimates of population size from other provinces or states within the range of the yucca moth. It is suspected that moth abundance is sustainable throughout most of the species' range (around and south of the Missouri River) as a result of their close proximity to other yucca populations, with the exception of ecologically marginal populations such as those at high elevations (Dodd and Linhart 1994).

LIMITING FACTORS

There are a number of natural and anthropocentric factors that may limit the distribution of yucca moths in Alberta. Most factors lead to the reduction of moth access to soapweed, which limits the interaction between the two species.

Natural Limiting Factors

1. Peripheral Distribution and Isolation. - Yucca moth distribution in Alberta is limited to locations where soapweed occurs, reproduces sexually and retains fruit. Yucca moths are physiologically limited by temperature and probably can survive only on south-facing, highly eroded, dry slopes, similar to the habitat characteristics of its host. At the northern edge of their range, moths not in these ideal locations exhibit lower fecundity; soapweed plants not located on south-facing slopes have fewer ovipositions, fewer fruit and lower larvae production than those moths that do occur in ideal locations (D. Hurlburt, unpubl. data). Further, the plant exists over 200 km north (in Fox Valley, SK) of the most northerly known location of the moth (Hurlburt 2001); hence it is probable that the moth is more restricted by latitude than the plant and cannot use the plant right to the edge of its range.

Alberta populations of soapweed are isolated from other populations in the main range by a minimum of 200 km, with little intervening native habitat in which soapweed could live (D. Hurlburt, unpubl. data). Isolation of Alberta's soapweed populations could prevent re-colonization of yucca moths in these sites should they become extirpated since adult yucca moths are particularly weak flyers, are short-lived and are likely incapable of dispersing long distances over inhospitable terrain (Kerley et al. 1993, Marr et al. 2000, J. Addicott, pers. comm.). Although other insects, such as aphids, ride storm fronts and can expand their distribution considerably, there is no evidence to suggest that this could occur with yucca moths. There are no records of moth-depauperate populations being recolonized by yucca moths. Further, there is evidence to suggest that small, declining peripheral populations of soapweed may not contain enough plants to sustain yucca moths (Dodd and Linhart 1994, D. Hurlburt, unpubl. data).

2. Ungulate Herbivory. - Floral and inflorescence herbivory by pronghorn (*Antilocapra americana*) and mule deer (*Odocoileus hemionus*) appears to play a large role in the persistence of the mutualism in some years and on some sites. Pronghorn eat individual yucca flowers; whereas mule deer most often eat the entire flowering stalk. When the number of inflorescences is low, because of small population size or low flowering, herbivory has been high (between 80% and 100% of flowers). In episodes of high flowering, herbivory has been low. The activities between yuccas and yucca moths in determining the outcome of the mutualism is over-ridden in times of high herbivory; that is, the nature of the

interactions between the yucca and yucca moth has little effect on their reproductive success because the deer and pronghorn consume most of the flowers and/or fruit. Complete or large reductions in fruit production can lead to complete reproductive failure of moths (D. Hurlburt, unpubl. data).

The date and type of herbivory of individually marked inflorescences, flowers and fruit were recorded to evaluate the magnitude and timing of herbivory on the success of the mutualism between years and sites. In 2000, herbivory by antelope caused a major loss of flowers during the peak flowering season at the Onefour site (Hurlburt 2001). Over the entire flowering season, 1328 of 2943 flowers were consumed; 47% of eaten flowers were newly opened (less than one day of age). However, in 1999, less than 2% of flowers were consumed at the same site even though the abundance of antelope appeared to be similar between years (Hurlburt 2001). Several populations in Montana exhibited the same patterns (D. Hurlburt, pers. obs.).

In 1998, Csotonyi and Hurlburt (1999) discovered that 80% of inflorescences at the Pinhorn site were clipped or entirely consumed by large herbivores. During the summer of 1999, less than 1% of flowers at Pinhorn were eaten during the flowering season, although an increase in herbivory did occur later in the season after unpollinated flowers were shed. Mule deer destroyed 100% of inflorescences flowering at the Pinhorn site in 2000. Artificial removal of flowers, in a unpredictable population of flowering plants, causes a decline in fruit production and moth survival. This has the potential, through decreased recruitment, to lead to long-term population decline in isolated peripheral populations (Kerley et al. 1993). Apparently this problem has been exacerbated in recent years by drought and the resulting absence of other vegetation for ungulates to feed on in the area (D. Hurlburt, pers. obs.).

3. Insect Herbivory. – The mutualistic relationship between yucca and yucca moths is also confounded by the presence of a newly recorded, non-pollinating moth, (*Tegeticula corruptrix*) (a species closely related to the yucca moth) (Perry 2001, D. Hurlburt, unpubl. data). It does not pollinate, but lays eggs in early-stage yucca fruit. These non-pollinators may impact the yucca/yucca moth mutualism by laying enough eggs in the yucca fruit that their larvae consume all the seeds (Addicott 1996). This results in competition with yucca moth larvae for food and limits sexual reproduction of the plant.

In other yuccas, the larvae of pollinating yucca moths limit exploitation by non-pollinators because the yucca moth larvae outcompete the non-pollinator's larvae (James 1998). On average, despite limitation by pollinators, non-pollinators ate 30% of seeds. In fruit with few or no pollinator larvae, all seeds were occasionally consumed by non-pollinators (James 1998). In southern Alberta, these non-pollinating larvae are abundant in some years and in localized areas and on average can consume up to 40% of seeds (D. Hurlburt, unpubl. data).

Additionally, ants can greatly reduce the availability of yucca flowers in which moths oviposit, and may kill moths that reside in flowers on which the ants are patrolling. Ants reduce the availability of yucca flowers by chewing on buds and subsequently causing the premature abscission of those buds. Some plants lose up to 90% of their buds through ant damage (D. Hurlburt, pers. obs.). Aphids also attract ants to yuccas, but ants are present even in the absence of aphids. Any insect encountered on a yucca plant that is not an aphid, is either disturbed by the ant so that it moves away, or it is caught and consumed (Perry 2001).

4. Wind. - Periodically, intense winds of up to 100 km/hr greatly affect the availability of

soapweed to moths and may eliminate developing larvae through premature removal of fruit from the stalk. During extremely windy days in 1999, over half of the flowers and young fruit at the Onefour site and 100% of flowers at the Pinhorn site were blown off. Individual plants located at the tops of coulee slopes or on the prairie flats were particularly susceptible. This kind of wind damage has not been recorded for any other yucca location (J. Addicott, pers. comm.) and is a major limiting factor in some years. During peak flowering, windstorms can destroy 25% to 35% of flowers produced in a single 24-hour period (D. Hurlburt, unpubl. data). Wind also makes it more difficult for pollinators to fly among inflorescences to collect pollen or to pollinate; moths remain in tightly closed yucca flowers during extreme periods of wind (D. Hurlburt, pers. obs.).

Anthropogenic Limiting Factors

5. Agricultural Activities. - Agricultural practices have restricted soapweed to unarable land in many areas of Montana (D. Hurlburt, pers. obs.). With the exception of grazing, agricultural activity is not a prevalent threat to soapweed or the yucca moth in Alberta; however, it is possible that an increase in such activity may take place in the future.

In both Alberta locations, soapweed and its moths must coexist with cattle and current grazing practices. Fortunately most plants occur on steep rocky slopes that are not preferred by cattle; however, those on the prairie and at the tops of slopes and in Onefour are particularly susceptible and most of their flowers and fruit were eaten by cattle in 2001. In the past, the Onefour Research Substation has not pastured cattle in the area of soapweed plants during flowering and fruiting; however, during periods of drought, such a luxury can not be afforded because feed for cattle is in short supply (I. Walker, pers. comm.). Although the plants in Pinhorn are accessible to cattle, grazing has not been a problem in recent years – typically mule deer consume all of the stalks shortly before or upon the beginning of flowering (D. Hurlburt, pers. obs.). Yucca populations in the southwestern United States are routinely decimated by grazing cattle (J. Addicott, pers. comm.) and it is plausible that grazing could become a substantial threat in Alberta.

Within Alberta, an estimated two-thirds of original grasslands have been lost to cultivation (Samson and Knopf 1994); however most areas inhabited by soapweed and its pollinator are not ideal for cultivation and are therefore, under no immediate threat. Strip-farming and irrigation are prevalent immediately across the coulee from the soapweed in Montana and these activities could take place on the flats immediately adjacent to the plants in Alberta. In the past 25 years, soapweed has spread onto these flats in a northerly direction (Csotonyi and Hurlburt 1999) and these clones and the spread of the population would be immediately threatened by intensive agricultural practices.

Widespread use of herbicides and insecticides could cause plant and moth mortality and reduce reproductive success. Currently, herbicides are only used to eliminate individual weedy plants near the Onefour soapweed site. Soapweed throughout the Great Plains are routinely killed through tilling and by the use of Round-up (D. Hurlburt, pers. obs.). In Montana, soapweed plants along roadsides sprayed for weeds tend to have fewer ovipositions and produce few fruit (D. Hurlburt, pers. obs.).

6. Traffic - Both Alberta sites are well known and accessible by road; as a result, both locations are visited daily during the summer and fall by naturalists, hunters, ranchers, border patrol and archeologists. Plants have been destroyed at both locations by off-road traffic and in one case, a vehicle was noted to be deliberately running over soapweed plants on the prairie at Onefour (D. Hurlburt, pers. obs.). Soapweed seedlings are more likely to occur on the disturbed soil of roads than in other locations; however, rarely do these seedlings survive more than one growing season

(D. Hurlburt, unpubl. data). Off-road traffic in these areas has destroyed cryptogamic soil crusts and caused an increase in erosion (D. Hurlburt, pers. obs.). A more concerted effort is required to make the public aware of the problem.

7. Horticultural and Medicinal Uses. - There are numerous examples of soapweed in household gardens in southern Alberta, transplanted from both the Onefour and Pinhorn population (Hurlburt 2001). One ranch in the area has well over a dozen soapweed plants in its garden, all from the declining Pinhorn population (D. Hurlburt, pers. obs.). None of the transplanted soapweed plants have shown any sign of oviposition or pollination by the moth (Hurlburt 2001). Such practices, although discouraged, probably will not affect the long-term success of the plant or the moth.

Other species of yucca (e.g., *Yucca elaphantipes*) that are commercially available in greenhouses, are found in household gardens across Canada. There has been no documentation of these plants having ovipositions or fruit or of observations of moths among their flowers. Although it is plausible that these small, isolated plants (native and non-native) could experience visitation by yucca moths, it is unlikely that they could support moth populations in large numbers or for any length of time. Yucca flowers usually need several visits from moths to ensure successful pollination (D. Hurlburt, unpubl. data) and most species and populations require cross-pollen for fertilization. Further, these commercial species may not be pollinated by *T. yuccasella*.

There has been interest in the collection of seed for the development of nursery stock and the collection of roots and petals for herbal remedies in Canada. Fruit production is extremely low some years, and when combined with seed collection, could very well jeopardize the viability of Alberta populations. To date, the importance of the few, high-fruiting years relative to the more frequent, low-fruiting years in maintaining soapweed populations is unknown. Although Alberta soapweed populations will never be harvested by large commercial operations because of their small population size, they could be threatened by smaller, grassroots-based harvesting (Hurlburt 2001).

SPECIAL SIGNIFICANCE OF THE SPECIES

The yucca moth (*Tegeticula yuccasella*) is the sole pollinator and predator of seeds in the soapweed, a long-lived, arid-region perennial with "Threatened" status in Canada (COSEWIC 2002). This unique relationship is called an obligate mutualism because neither species can survive without the other. Moth larvae feed only on yucca seeds, and in turn, yuccas can only produce seed if they are pollinated by yucca moths. Mutualistic relationships, such as those between yuccas and yucca moths, epitomize the essence of food-web interactions. The fate of many plants may depend on preserving their mutualistic relationships with pollinators and with the web of organisms that affect both plant and pollinator (Bond 1994, Kearns and Inouye 1997).

The patchy distribution of northern yucca populations, coupled with the limited dispersal ability of yucca moths, may reduce gene flow among yucca moth populations relative to that of more continuously distributed populations (Massey and Hamrick 1998). Isolation and extreme environmental effects may introduce selective pressures to the population that are unique or relatively severe (Lesica and Allendorf 1995), leading to more rapid genetic divergence than expected. In comparison with populations occupying the range centre, peripheral populations of yucca moths may be adapted to a greater variety of environmental conditions. Thus, peripheral populations should be pre-adapted to anthropogenic disturbance or climate change that may threaten populations across the remainder of the species range (Lomolino and Channell 1998). Although genetic evidence to

support this does not exist, yucca moths in Alberta exhibit unique behavioural characteristics. These moths have a longer flight season and apparently lay their eggs in different locations of the flower relative to moths residing further south (D. Hurlburt, unpublished data).

STATUS DESIGNATIONS

1. Alberta. - Yucca moths were not included in the 1996 Status of Alberta Wildlife document (Alberta Wildlife Management Division 1996), nor were they assessed in *The General Status of Alberta Wild Species* 2000 (Alberta Sustainable Resource Development 2001).

2. Other areas. - To date, the status of the yucca moth has not been evaluated by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), although this was recommended by Csotonyi and Hurlburt (1999). Its sole host, the soapweed is designated as "Threatened" by COSEWIC and faces similar threats to its pollinator. It is plausible that the moth is of increased risk because of its short lifespan relative to that of its host.

The species does not have a National Heritage Status rank in Canada or the United States, nor does it have a Global Heritage rank (NatureServe 2001). Based on literature, research and observation, the author believes that the species should receive a rank of N5, G5 at the United States and Global levels and in Canada be ranked N1, the same as its host, the soapweed.

RECENT MANAGEMENT IN ALBERTA

1. Status Evaluation. - Csotonyi and Hurlburt (1999) and Hurlburt (2001) recommended that the status of the yucca moth be evaluated and that the species be considered for protection. Before 1998, there were no useful data available on soapweed or the yucca moth. This report is the first formal attempt to assess the species status in Alberta and in Canada. To date, there have been no steps to manage or protect the species, nor its host, the soapweed.

2. Research. - Since 1999, the author has been conducting and supervising research in Alberta and northern Montana to assess how environmental and biological conditions at the northern edge of a range influence the coordination and the persistence of the interaction between soapweed and its moth. More specifically, the success of the relationship in relation to 1) demography, 2) life history synchrony, 3) yucca breeding systems and 4) presence of other species that feed on yuccas, is researched through field studies and by the computer modeling of life history phenologies. This project is unique because studies investigating the preservation of species interactions are uncommon; biologists tend to focus on single species. It is hoped that the investigation of the plant/pollinator dynamics of this interaction will be used to make optimal management decisions for the conservation of yucca, the yucca moth and their surrounding habitat in Canada (Hurlburt 2001).

3. Recovery. - Initial steps are being taken to establish a species recovery team and plan for the soapweed in Canada. The author and other knowledgeable individuals believe that the Pinhorn soapweed population can become viable. The plants cover a small area and could readily be protected from herbivory with deer-proof fencing as was first recommended in 1999 (Csotonyi and Hurlburt 1999). Further, moths could easily be transported from Onefour and released in Pinhorn; such relocations are common in yucca research, although for research purposes rather than for management.

SYNTHESIS

The limited distribution and small effective population size (low numbers of plants and low flowering levels) of soapweed at the northern edge of its range, makes the yucca moth susceptible to population declines in Alberta. Recent studies in Alberta indicate moth abundance in the Onefour population is similar to that of the main range, but the moth in the Pinhorn population is in severe decline (possibly

being extirpated through herbivory by wild ungulates). However, there is little available literature on northern populations of *T. yuccasella*. The species' historic distribution and long-term population trends in Alberta are unknown and there is no information on most other parts of its distribution. Only in recent years has there been a vested interest in the preservation of non-agricultural invertebrate species, and as a result, few such insect populations have been monitored from a conservation perspective over the long-term. It is recommended that annual (or at least biannual) assessments of yucca moth populations be monitored in Alberta to determine population trends. Further, more detailed studies of the life history and genetics of yucca moths are needed to facilitate the development of conservation management strategies. The Pinhorn population could become viable through protection with deer-proof fencing and with the transport of moths from the Onefour population.

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APPENDIX 1. Definitions of selected legal and protective designations.

A. The General Status of Alberta Wild Species 2000 (after Alberta Sustainable Resource Development 2001)

2000 Rank	1996 Rank	Definitions
At Risk	Red	Any species known to be at risk after formal assessment and designation as Endangered or Threatened in Alberta.
May Be At Risk	Blue	Any species believed to be at risk. These species will require a detailed assessment for possible formal designation as Endangered or Vulnerable.
Sensitive	Yellow	Any species known to be, or believed to be, particularly sensitive to human activities or natural events.
Secure	Green	Any species known to be, or believed to be, not at risk.
Undetermined	Status Undetermined	Any species where not enough information exists to adequately use the ranking system (exceptional cases only).
Not Assessed	n/a	Any species known or believed to be present but which have not yet been evaluated.
Exotic/Alien	n/a	Any species that have been introduced as a result of human activity.
Extirpated/Extinct	n/a	Any species no longer thought to be present in the jurisdiction or are believed to be extinct.
Accidental/Vagrant	n/a	Any species occurring infrequently and unpredictably outside their usual range.

B. Alberta Wildlife Act

Species designated as "Endangered" under Alberta's *Wildlife Act* include those defined as "Endangered" or "Threatened" by *A Policy for the Management of Threatened Wildlife in Alberta* (Alberta Fish and Wildlife 1985):

Endangered	A species whose present existence in Alberta is in danger of extinction within the next decade.
Threatened	A species that is likely to become endangered if the factors causing its vulnerability are not reversed.

C. Committee on the Status of Endangered Wildlife in Canada (after COSEWIC 2002)

Extinct	A species that no longer exists.
Extirpated	A species that no longer exists in the wild in Canada, but occurs elsewhere.
Endangered	A species facing imminent extirpation or extinction.
Threatened	A species that is likely to become endangered if limiting factors are not reversed.
Special Concern	A species of special concern because of characteristics that make it particularly sensitive to human activities or natural events.
Not at Risk	A species that has been evaluated and found to be not at risk.
Data Deficient	A species for which there is insufficient scientific information to support status designation.

D. Heritage Status Ranks: Global (G), National (N), Sub-National (S) (after NatureServe 2001)

G1/N1/ S1	**Critically Imperiled**: Critically imperiled globally because of extreme rarity or because of some factor(s) making it especially vulnerable to extinction. Typically 5 or fewer occurrences or very few remaining individuals (<1,000) or acres (<2,000) or linear miles (<10).
G2/N2/ S2	**Imperiled**: Imperiled globally because of rarity or because of some factor(s) making it very vulnerable to extinction or elimination. Typically 6 to 20 occurrences or few remaining individuals (1,000 to 3,000) or acres (2,000 to 10,000) or linear miles (10 to 50).
G3/N3/ S3	**Vulnerable**: Vulnerable globally either because very rare and local throughout its range, found only in a restricted range (even if abundant at some locations), or because of other factors making it vulnerable to extinction or elimination. Typically 21 to 100 occurrences or between 3,000 and 10,000 individuals.
G4/N4/ S4	**Apparently Secure**: Uncommon but not rare (although it may be rare in parts of its range, particularly on the periphery), and usually widespread. Apparently not vulnerable in most of its range, but possibly cause for long-term concern. Typically more than 100 occurrences and more than 10,000 individuals.
G5/N5/ S5	**Secure**: Common, widespread, and abundant (although it may be rare in parts of its range, particularly on the periphery). Not vulnerable in most of its range. Typically with considerably more than 100 occurrences and more than 10,000 individuals.
GX/NX/ SX	**Presumed Extinct** (species) - Believed to be extinct throughout its range. Not located despite intensive searches of historical sites and other appropriate habitat, and virtually no likelihood that it will be rediscovered. **Eliminated** (ecological communities) - Eliminated throughout its range, with no restoration potential due to extinction of dominant or characteristic species.
GH/NH/ SH	**Possibly Extinct** (species) - Known from only historical occurrences, but may nevertheless still be extant; further searching needed. **Presumed Eliminated** (Historic, ecological communities) - Presumed eliminated throughout its range, with no or virtually no likelihood that it will be rediscovered, but with the potential for restoration, for example, American Chestnut (Forest).

E. United States Endangered Species Act (after National Research Council 1995)

Endangered	Any species which is in danger of extinction throughout all or a significant portion of its range.
Threatened	Any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range.

APPENDIX 2. Yucca moth (*Tegeticula yuccasella*) abundance data from the centre of the soapweed (*Yucca glauca*) range, United States.

Location	Year	Mean	Range	Source
Larvae per fruit				
Clinton, OK	1979	1.4 ± 1.9	0 - 8	Keeley et al. 1984
Gunnison, CO	1980	4.1	0 - 11	Addicott 1986
Poncha Springs, CO	1980	3.8	0 - 16	Addicott 1986
Wolf Creek, MT	1980	5.6	0 - 19	Addicott 1986
Clines Corners, NM	1980	0.7	0 - 2	Addicott 1986
Boulder Valley, CO	1986	8.17 ± 0.84	2-17	Dodd 1989
Buckingham Pk, CO	1986	7.70 ± 1.52	0-21	Dodd 1989
Jamestown, CO	1986	3.50 ± 1.32	0-6	Dodd 1989
Boulder Valley, CO	1987	19.73 ± 2.87	0 - 31	Dodd 1989
Jamestown, CO	1987	0.00 ± 0.00	0	Dodd 1989
County Rd 87, CO	1987	1.40 ± 0.31	0-3	Dodd 1989
Loma, MT	1999	4.64 ± 0.774		Hurlburt unpubl.
Loma, MT	2000	7.91 ± 1.851	0 - 19	Hurlburt unpubl.
Wolf Creek, MT	1999	6.29 ± 0.938		Hurlburt unpubl.
Fort Benton, MT	2000	4.85 ± 0.890	1 - 12	Hurlburt unpubl.
Fruit per inflorescence				
Mitchell, NB	1980	4.04 ± 0.45		Kingsolver 1984
Oelrich, SD	1980	3.08 ± 0.56		Kingsolver 1984
Canadian, TX	1980	3.00 ± 0.81		Kingsolver 1984
Alva, OK	1980	2.06 ± 0.44		Kingsolver 1984
Lake Scott, KS	1982	7.62 ± 0.35		Kingsolver 1984
Boulder Valley, CO	1986	5.18 ± 0.60	1 - 23	Dodd 1989
Buckingham Pk, CO	1986	3.11 ± 0.33	1 - 9	Dodd 1989
Jamestown, CO	1986	0.00 ± 0.00	0	Dodd 1989
Arapaho Prairie, NB	1993	0.72 ± 0.18		Moravec 1994
Arapaho Prairie, NB	pre-1993	3.23 ± 0.29		Moravec 1994
Loma, MT	1999	2.2 ± 0.46		Hurlburt unpubl.
Loma, MT	2000	0.08 ± 0.04	0 - 1	Hurlburt unpubl.
Wolf Creek, MT	1999	4.6 ± 0.80		Hurlburt unpubl.

APPENDIX 2. Continued

Wolf Creek, MT	2000	2.00 ± 0.75	0 - 16	Hurlburt unpubl.
Fort Benton, MT	2000	3.24 ± 0.57	0 - 12	Hurlburt unpubl.
Moths per flower				
Arapaho Prairie, NB	1993		1 - 4	Moravec 1994
Loma, MT	2000	1.587 ± 0.481		Hurlburt unpubl.
Emergence holes per fruit				
Mitchell, NB	1980	4.02 ± 0.46		Kingsolver 1984
Lake Scott, KS	1982	3.26 ± 0.38		Kingsolver 1984
Lake Scott, KS	1983	2.56 ± 0.50		Kingsolver 1984
Meade, KS	1980	0.64 ± 0.15		Kingsolver 1984
Alva, OK	1980	0.46 ± 0.11		Kingsolver 1984
Geary, KS	1980	1.10 ± 0.29		Kingsolver 1984
Neodesha, KS	1980	4.88 ± 0.76		Kingsolver 1984
Ovipositions per fruit				
Loma, MT	1999	24.80 ± 3.866		Hurlburt unpubl.
Wolf Creek, MT	1999	23.71 ± 1.819		Hurlburt unpubl.
Loma, MT	2000	7.91 ± 1.851	0 - 19	Hurlburt unpubl.
Fort Benton, MT	2000	4.846 ± 0.89	1 - 12	Hurlburt unpubl.

APPENDIX 3. Yucca moth populations in Alberta and Canada. Point numbers correspond to points plotted in Figure 1.

Point	Location	Co-ordinates	Source	Comments
1.	Lost River, AB	49°00' 00" N 110°26' 00" W	Milner 1977 Csotonyi & Hurlburt 1999 Hurlburt 2001	Population is self-sustaining with extreme variation in moth abundance among years
2.	Pinhorn Grazing Reserve, near Milk River, AB	49° 05' 12" N 110° 50' 04" W	Csotonyi & Hurlburt 1999 Hurlburt 2001	Population is in severe decline with only one female moth being observed in four years of study and no fruit production in a minimum of five years.

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